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A WATER-IMMERSION TECHNIQUE FOR THE STUDY OF MOBILITY OF A PRESSURE-SUITED SUBJECT UNDER BALANCED-GRAVITY CONDITIONS

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SUMMARY

A technique for simulating zero-gravity performance of an astronaut in a pressurized spacesuit by complete water immersion has been developed and investigated. The technique allows the pressure-suited subject to move in six degrees of freedom without the encumbrance of connecting lines or hoses or other supports and further permits performance simulation of long-duration tasks.

Experiments were made to demonstrate the relationships between the maneuvers performed by a pressure-suited subject under weightless conditions produced by water-immersion and zero-gravity aircraft flights and those performed under full-gravity conditions. An overall description of the test procedures, pressure suit and modifications, self-contained gas-supply breathing system, and methods for obtaining neutral buoyancy is provided.

The tests demonstrated that the simulation technique is useful for premission determination of critical operational characteristics relating to spacecraft and spacesuit design under conditions of zero gravity. In addition, the physical capabilities of man and his ability to perform useful work and maneuvers in a pressurized suit under simulated zero-gravity conditions can be demonstrated by this technique. Test variables included time, suit pressure, and simulation mode. Comparison of the subject's motion behavior between the aircraft and water-immersion tests showed that the water-immersion technique is valid where the velocities are low.

INTRODUCTION

Current NASA studies of manned space stations and other extended-mission manned space vehicles indicate the requirement for astronaut performance of extravehicular tasks in the zero-gravity vacuum environment of space while encumbered by a full pressure suit. These tasks will include ingress and egress through air locks, intervehicular crew and cargo transfer, erection of external equipment and experiment hardware, inspection and maintenance, and the performance of various extravehicular scientific tasks and measurements.

Current data on astronaut performance in reduced gravity conditions are derived from simulations comprising three experimental modes: (1) the partial-gravity mode produced by the use of a component of earth "g" as in reference 1, (2) frictionless air bearing and suspension systems, and (3) the zero-gravity mode produced by aircraft flying a Keplerian trajectory. The ground experiments comprise simulation where all or part of the weight of the subject is supported by various devices such as cables and/or air bearing platforms. The cable systems restrict the subject's performance to confined spaces and limited degrees of freedom because of the fixed constraints of the attachment and suspension systems. Air bearing platforms limit the motions to a plane of operation. The results of these ground tests are not completely applicable to studies of the pressure-suited astronauts operating under zero-gravity conditions. Recent studies conducted under contract NAS1-4059, "A Study of the Performance of an Astronaut During Ingress and Egress Maneuvers Through Spacecraft Airlocks and Passageways," (briefly described in ref. 2, and reported in more detail in ref. 3) show that the results of ground simulation under normal-gravity conditions had little direct relation to similar maneuvers performed aboard the zero-gravity C-131-B aircraft. Although the C-131-B aircraft does provide a zero-gravity mode, it is subject to severe limitations because of the limited time available under zero-gravity conditions. Weightless simulation by aircraft flying a Keplerian trajectory is limited to test durations of 10 to 30 seconds.

An investigation was therefore undertaken to assess the feasibility of operating a self-sustaining, pressure-suited subject in a neutrally buoyant condition in water and to determine significant problem areas qualitatively. The present investigation was undertaken on the premise that this water-immersion test would simulate the motion performance under zero- or balanced-gravity flight conditions. Work is being continued on the application of this technique to various detailed problem areas of extravehicular space activities to which the method is suitable; this paper is limited to a presentation of the feasibility of the simulation technique as applied to initial work on the air-lock ingress-egress problem and is not intended as an analysis of the ingress-egress problem on which the technique is being applied. The Navy Mark IV Modification-0 full pressure suit was used in the water-immersion experiments presented in this paper.

Water-immersion techniques for the simulation of weightlessness are not new. Stone and Letko (ref. 4) reported on preliminary static experiments to determine the feasibility of simulating weightlessness by water immersion, particularly with regard to physiologic and vestibular responses of such a procedure. In these experiments the subject equipped with scuba gear was located in a fixed chair arrangement in a tank of small dimensions. The tank was filled with water and rotated so as to obviate the otolithic sensations. Similar investigation was carried out by Lockheed Aircraft Corp. (ref. 5) to study single manned crew station performance. Graveline (ref. 6) has performed significant numbers of experiments of a similar nature. The simulation technique described herein differs from those of references 4 to 6 in two important characteristics. First, the present simulation technique is primarily designed to investigate the external motion and performance characteristics of a suited subject in a weightless state in which he is permitted to move about freely in six degrees of freedom while unrestricted by connecting lines. Second, this simulation technique does not provide for maintaining the internal body zero-gravity effects, that is, the physiological effects of the simulation on the internal organs, as reported in reference 6.

A summary film, NASA Film No. L-849, illustrating the early feasibility tests and important aspects of the test procedure is available on loan. A film request card is bound in the back of this report.

Measurements in this investigation were taken in the U.S. Customary System of Units, but in conformity with recent efforts of the National Aeronautics and Space Administration to introduce the International System of Units (SI) into its research reports, the pertinent measurements are presented also in the International System of Units. Historical information on SI Units, factors relating the two systems of units, and standard abbreviations are given in reference 7.

APPARATUS

Pressure Suits

The U.S. Navy Mark IV Modification-0 full pressure suit was chosen for the water-immersion tests in order to approximate the experimental extravehicular full-scale suit configurations for the following reasons:

(a) The mobility afforded by the Mark IV suit is reported to approximate closely that afforded by presently used pressure suits.

(b) The availability of the Mark IV suit is commensurate with the program budget and time schedules involved.

The Mark IV suit consists of a hermetically sealed inner rubber layer and an outer nylon restraint garment. Entrance to the body of the suit is afforded by a circumferential double sealed zipper. Appropriate tab inserts and laces are provided for lengthening and shortening the arms, legs, torso length, and circumference. The body of the suit terminates at the neck in an open bearing ring and seal which mates with the helmet component and serves as a pivot for the helmet. Adjustable cable restraints are provided to maintain the helmet position relative to the torso when the suit is pressurized. A breathing regulator, communication unit, internal head-restraint component, breathing-gas and pressurization control unit, and visor are incorporated in the high-strength plastic helmet. Two quick-disconnect ports are provided on the left of the suit body for vent air and g-suit inflation. An additional port is provided on the right side which acts as an exhaust port to the sensing element of the regulator. An internal tubular vent system is supplied with the suit which cools the suited subject. The nylon reinforced rubber feet of the suit are integral with the legs of the suit and are contained by insulated flight boots. The Mark IV suit used in the tests is shown in figure 1.

Pressure-Suit Modifications

The Mark IV suits were originally designed to operate in conjunction with the U.S. Navy high-performance aircraft. The suits are normally operated in an unpressurized condition with the pilot in a seated position. In event of cabin depressurization or bailout, the suits are automatically pressurized. The suits are designed for normal operation with a two-gas system, for example, ventilation gas passes through the torso of the suit from the engine compressors and oxygen enters the helmet from the separate oxygen storage system. During the tests reported in this paper, air was used instead of oxygen to avoid possible oxygen toxicity since the absolute pressure in the suit would always be greater than atmospheric pressure. The suit system was modified by blocking the ventilation system and adding an air-supply tank and first-stage breathing-gas regulator to the suit system.

Figure 2 is a diagram of the modified breathing and pressurization system provided for the tests. High-pressure air storage was provided by a scuba air tank and backpack element which comprises a 2500 psig (17.2 MN/m^2), 70 cu ft (1.98 m^3) storage bottle combined with a first-stage 50 to 90 psig (345 to 621 kN/m^2) regulator and low-level tank capacity alarm unit. The 50 to 90 psig (345 to 621 kN/m^2) air enters the second-stage regulator on the helmet through a short flexible line provided with quick disconnects. After the visor is closed, the visor seal is pressurized, sealing and locking the visor in place. Breathing air is admitted to the helmet through the regulator in the helmet upon subject demand. The demand regulator is closed when the subject exhales and the used air is expelled into the torso of the suit through a check valve in the neck seal, thereby pressurizing the suit. The excess ports on the left side of the suit were closed off by blind disconnects. Suit pressurization is determined by the controller setting on the right side of the suit. The controller contains a spring-loaded relief valve which can be preset from 0 to 5 psig (0 to 34.5 kN/m^2). The modified self-contained breathing pressurization air supply allows the subject to operate freely in confined spaces and through hatches, and to perform different maneuvers unrestrained by connecting lines and hoses, for periods of time up to $1\frac{1}{2}$ hours.

Ordinary athletic shoes were used instead of the more rigid flying boots supplied with the suit, because they improved mobility in confined spaces and permitted the subject to operate with greater ease and dexterity.

Model Air Lock

For the demonstration of the feasibility of the water-immersion simulation, the existing Langley Research Center transparent air-lock test model was used. The air-lock model (fig. 3), comprises a cylindrical passageway 72 inches (1.83 m) in length and 48 inches (1.22 m) in diameter. Three hatches allow entry into the passageway. One end contains a circular 32-inch-diameter (0.81-m) hatch which opens outward and the other end contains an oblong 36-inch × 28-inch (0.91-m × 0.71-m) hatch which opens inward. The third is a 36-inch-diameter (0.91-m) circular hatch on the side of the air lock. The hatches are representative of those currently employed in manned spacecraft designs. In some of the tests, the hinges were changed from the right side of hatch to the left. The air-lock model shown in figure 3(a) was used in the ground and aircraft tests and the model in figure 3(b), in the water-immersion test.

TEST PROCEDURES

Techniques and Measurements

To investigate the feasibility of simulating astronaut task performance in a weightless condition by means of the water-immersion technique, a pressure-suited subject was maintained in a neutrally buoyant condition and was required to perform typical tasks. These tasks were also performed in an aircraft flying a zero-gravity trajectory and on the ground under full-gravity conditions to study the validity and applicability of the water-immersion technique. Test variables included time, methods of operation, and suit pressures from 1 to 3.5 psig (6.9 to 24.1 kN/m^2) relative to local ambient pressure.

A complete photographic record was made by an immersed 16-mm motion-picture camera (fig. 6) positioned normal to the longitudinal axis of the air lock. A standard frame rate of 24 frames per second was used in all tests. An optical grid positioned behind the air lock and dimensioned markings 2 feet (0.61 m) apart on the outside of the air lock were used in conjunction with the motion pictures to measure velocities of the subject, time to perform specific tasks and subtasks, and body position. The dimensioned markings but not the optical grid were also used in the ground and aircraft tests.

Suit Balancing for Neutral Buoyancy

Prior to the performance of experiments in the water-immersion simulation, a determination of the subject's physical measurements was made and the subject was subsequently fitted to one of the standard full pressure suits. To counteract the inherent positive buoyancy of the pressure-suited subject, ballast weight was added both inside and outside the suit. The internal ballast was provided by modifying a standard g-suit to include weight distributed in the lower leg and abdominal areas. The external weights comprised a set of distributed mass elements positioned in a symmetrical pattern at or near the center of mass of the major body elements. In this manner the subject is statically balanced as to whole body and body pitch and roll. The placement of external weight is shown in figure 4. The subject is tested for neutral buoyancy and proper static stability about all body axes for each suit-pressure level. During the course of the experiments, it was found that the technique for establishing neutral buoyancy and stability had to be repeated at frequent intervals to provide for the growth and aging characteristics of the suits. The first sequences of the film supplement (L-849) illustrate some of the balancing operations used to attain neutral buoyancy.

Water-Immersion Tests

Photographs of a pressure-suited subject during the water-immersion simulation are shown in figure 5. These figures illustrate hatch operation during ingress, the turnaround maneuver, and egress. This task sequence was established to provide a sufficiently broad performance spectrum for subsequent analysis.

The individual tests were initiated by towing the neutrally buoyant subject to the test area. This was done by the safety monitor who was equipped with scuba gear. The tests were conducted in the air lock which was immersed in 11 feet (3.4 m) of water in a swimming pool. The air lock was maintained in a stable configuration on the pool floor by adding approximately 240 pounds (109 kg) of lead ballast and locking the wheels. The suited subject remained at the immersed site during the entire run series but was returned to the shallow end of the pool during the camera reloading period, and for safety reasons.

Full-Gravity Ground Tests

Full-gravity ground tests were conducted with the transparent model air locks as shown in figure 3(a) except that a ramp was provided external to each hatch to facilitate ingress and egress. Ballast weights were not required on the test subject.

Zero-Gravity Aircraft Tests

Zero-gravity aircraft simulation tests were performed aboard the C-131-B aircraft (at Wright-Patterson Air Force Base) at altitudes from 8000 to 12 000 feet (2438 to 3658 m). Because of the limited zero-gravity time during the Keplerian trajectory, the ingress-egress maneuver had to be broken down into six parts. These maneuvers consisted of entry into the air lock, turnaround, closing the entry hatch, additional turnaround, opening the exit hatch, and exit from the air lock. Tests in the zero-gravity aircraft are further complicated by the requirement that each test be started and ended by a 2.5g pullout, during which the subject was required to lie on the bottom of the air lock. This maneuver is necessary for the aircraft to fly the trajectory attendant with zero-gravity aircraft flight. In order that the subject prepare himself for the pullout phase, the test director gives an audible warning several seconds before pullout. The major factor of the aircraft test which complicates the evaluation of weightless operation is the sense of urgency imparted to the subjects to complete the maneuvers rapidly because of the time and dynamic constraints.

RESULTS AND DISCUSSION

The suited astronaut will be called on to perform two distinct types of maneuvers in conjunction with presently contemplated space station and planetary missions. These maneuvers are (1) free-motion maneuvers such as those occurring during intervehicular transfer in free space or (2) maneuvers constrained by space limitations such as those occurring during ingress and egress, and extravehicular maintenance and repair. These second maneuvers are the subject of this simulation feasibility demonstration.

Drag

The ingress-egress maneuver characterizes a set of maneuvers in which the weightless astronauts will operate in a pressurized spacesuit within the volumetric constraints of a spacecraft air-lock system. Due to the sensitivity of this procedure to overall mission safety and more directly due to the performance restraints imposed on the astronaut by the presently configured pressure suits, these maneuvers can be classified as having low relative velocities. The most significant limitation to the water-immersion simulation derives from the drag and damping properties associated with the performance of motions while the subject is immersed. Task and motion analysis correlated with ground normal-gravity experiments permitted the estimation of an apparently normal range of motion and velocity. The range of the subject's forward velocities was considered to be between 0 and 1.75 fps (0 and 0.53 m/sec) and the range of motions was considered to be defined by the existing dimensions of the air lock. Figure 7 shows the estimated drag envelope for the suited subject in erect, semicrouch, and prone positions for both the aircraft and water-immersion simulation. The drag was calculated from the average drag coefficient for zero roll as presented in reference 7. Figure 8 shows the envelope of velocities measured from motion pictures of the water-immersion tests during ingress-egress maneuvers for various suit pressures. For the body positions observed during these tests, the drag is small where the velocities are low. Comments by the subject indicate that the drag was of minor import in water for the aforementioned velocities and had little effect on his ability to maneuver compared with the greater effort necessary to overcome the resistance of the pressure suit. This conclusion was further substantiated by examination of a similar test series conducted on the ground and in the zero-gravity C-131-B aircraft.

Motions

Photographs of operations in figures 9 to 11 are shown to illustrate similarities and differences in the three modes of simulation. The motions and operating procedures performed by the suited subjects in the air lock were closely related for the water-immersion and aircraft modes. Significant operational differences were evidenced between these two modes and the ground normal-gravity mode.

Figure 9 presents a photographic sequence of the suited subject making passage through the transparent air-lock test model during water-immersion tests. The subject tends to move forward in an inclined body position during ingress in order to maintain forward visibility through the helmet faceplate. Forward motion in this mode requires the expenditure of very little effort.

The test subject reported that the turnaround maneuver as illustrated in sequences (d) and (e) of figure 9 required more effort than any other task. The subject must sharply bend the knees, hips, and neck attachment of the pressurized suit in order to perform a turnaround in the 4-foot (1.2-m) diameter of the air lock. The turnaround in this case was performed to close and lock the hatch through which the subject had entered. The subject then performs an additional turnaround maneuver in order to open the hatch at the opposite end of the air lock as shown in sequence (g) of figure 9. The egress maneuvers, illustrated in sequence (h) of figure 9, required very little effort; however, maneuvers of exit without the use of handholds required considerable skill to control body position. Passage through the air lock showed only minor differences with this sequence.

Figure 10 presents a photographic sequence of the subject making passage through the air-lock test model during the zero-gravity aircraft tests. The subject's operational mode in performing the various subtasks (fig. 10) was very similar to that in the underwater simulation shown in figure 9. The turnaround maneuver in the zero-gravity aircraft tests was not possible at suit pressure above 2.5 psig (17 kN/m^2), since the subtask required more than the 10 seconds of available zero-gravity time. The same test subject performed the turnaround adequately in the water-immersion mode. Other ingress-egress maneuvers aboard the aircraft showed close similarity with those of the water-immersion mode. The task performance sequence of the water-immersion simulation appears to approximate the total problems anticipated during ingress and egress more closely because of the test duration, associated fatigue factors, and the unrestricted operating time. The aircraft mode, however, is necessary to examine the validity of and to supplement the water-immersion simulation of weightless performance.

Figure 11 presents a photographic sequence of the subject performing the ingress-egress maneuver through the test model air lock during full-gravity ground tests. In comparing this test with previous tests, it should be noted that the side hatch frame was located on the opposite side of the air lock or 180° from its position in the other tests. Entry into the air lock, as noted in sequence (c) of figure 11, requires considerably more effort than was necessary in the underwater and aircraft simulations. The subject is required to move forward on his hands and knees in the pressurized suit. Difficulty was experienced by the subject in negotiating his legs over the approximately 6-inch (15.2-cm) ledge on ingress because of the force necessary to raise his knees to a sufficient height. The air-lock model shown in figure 11 was inverted compared with its position in figures 9 and 10.

The turnaround task under full-gravity condition, as illustrated in sequences (d) and (e) of figure 11, was complicated by the cylindrical shape of the bottom of the air lock and the confined space available for maneuvering. Egress from the air lock presented similar problems of locomotion on the hands and knees and over a ledge as illustrated in sequences (g) and (h) of figure 11. The operational modes of the subject in performing the various subtasks showed very little similarity between tasks performed in the underwater and ground tests. The effort required by the subject at 3.5 psig (24.1 kN/m^2) suit pressure tired the subject more quickly in the ground tests than in the underwater weightless simulation. It can be seen from the sequence of figure 11 that the results of ground tests under full-gravity conditions are not applicable to predicting the performance of the astronaut in the weightless environment.

Task Time

Figure 12 presents a comparison of the total ingress-egress time at various suit pressures for the underwater, the aircraft, and ground tests. A direct relationship is evident in the time-pressure profile between the aircraft and underwater tests except when the subtask requires more time than is available in the aircraft trajectory. The total ingress-egress time is defined as the time from when the subject started to open the ingress hatch until he closed the egress hatch or exit. The time increments, based on a limited number of runs at different suit pressures, for the ground tests differ somewhat for those of the underwater and aircraft tests. A total of 28 tests were made in the three simulations.

Figure 13 presents subtask performance time at various suit pressures for the ground, aircraft, and underwater modes. The subtask performance for various tasks required comparable time during the aircraft and underwater modes; however, the turnaround maneuver was not always possible in the short duration of the aircraft tests. The time for performing the comparable subtasks for various suit pressures was not markedly different for the underwater and aircraft tests.

The results from similar experiments performed in the aircraft with the more exhaustive study made possible with the water-immersion technique are complementary, and the combination of modes can be used to provide a more accurate simulation for investigating the zero-gravity phenomena.

Applications

The technique developed herein provides a relatively inexpensive, useful tool for astronaut indoctrination and training. Astronaut training aboard zero-gravity aircraft has proven to be expensive, tedious, and of insufficient time periods to develop and analyze many procedures, techniques, and maneuvers.

The water-immersion technique should make an important contribution to manned spacecraft design, pressure-suit design, and to the better understanding of the capabilities of man and his ability to perform maneuvers and useful operations in the balanced gravity state. Further development of the water-immersion technique makes it useful for application to many additional manned spacecraft studies. It will be a useful tool in the study of astronaut capabilities and mobility. This information will be required for the design of manned space vehicles and related systems, and to establish performance limits and procedures for the astronauts. Man-machine relationships must be determined in order to design the system properly. One such example is the development of ingress-egress techniques and related systems. This maneuver forms one of the critical operations which must be repeatedly performed onboard the manned space vehicle. During the maneuver the sealed integrity of the living environment is momentarily broken. The astronaut is required to make a transition from the pressurized interior of the space vehicle to a self-contained existence in a full pressure suit and life-support unit in the hard vacuum environment. The level of cycling of this maneuver will depend upon the frequency of docking, crew supply and rotation, extravehicular maintenance, and station functions imposed by the mission.

Another use is for the study of intervehicular crew and cargo transfer functions. The logistic system for resupply of extended-mission manned space stations orbiting the earth is dependent upon practical means of transfer between space vehicles. Cargo-handling techniques need to be developed for zero-gravity conditions and the different modes, thoroughly analyzed.

In addition, the water-immersion technique should be useful for pressure-suit development and testing in the zero-gravity environment. Pressure suits developed for the lunar gravity environment are not necessarily efficient for zero-gravity conditions. Those suits which are comfortable for the astronaut traveling in a seated position in a transport vehicle, such as the Gemini, do not have the mobility and flexibility for efficient extravehicular operation. The suits used by the extravehicular astronaut need not necessarily be as rugged or heavy as those used by the lunar astronaut, and can be constructed to have increased flexibility, maneuverability, and freedom of movement.

The water-immersion technique can, in addition, be used to develop routine and emergency procedures for the astronauts on extended missions. Thorough development and analysis of procedures is necessary before any actual flight. The operational capabilities of the astronaut aboard the space vehicle will be of greater value if procedures are developed in advance.

In addition, the techniques of extravehicular erection, maintenance, and assembly of external structures by the astronaut must be developed to support design of equipment, modular space vehicles and space stations. Many phases of these tasks can be studied by water-immersion techniques of the pressure-suited astronaut.

In support of the preceding uses, this simulation can be enhanced by perfecting maneuvers and techniques by water immersion and using the Keplerian zero-gravity aircraft flights to examine the validity and astronaut performance further. The combination of the results from the two means of simulation are complementary and should increase the value of one another in studying extravehicular astronaut activities.

Furthermore, by adjusting the buoyancy of the test subject, partial-gravity simulation can be effected. It is possible to study many operations which the pressure-suited astronaut may be required to perform on the lunar surface, on other planets, or on a space vehicle providing a degree of artificial gravity.

Zero-gravity simulation methods will never replace actual orbital flights for obtaining data. However, the external motion performance of the pressure-suited astronaut can be reasonably well simulated in six degrees of freedom by the water-immersion simulation when the movements are less than approximately 2 fps (0.61 m/sec). The dynamics of such movements are not totally simulated because of the damping effects of the water. Traverse and other maneuver characteristics are, however, quite similar to those observed in Keplerian trajectory aircraft flights and actual orbital missions.

Equipment for studying task performance by water-immersion techniques need not be elaborate or expensive, but must be balanced to neutral buoyancy. Certain flight articles, however, would require considerable modification since communication and electrical equipment could not be used underwater.

CONCLUDING REMARKS

Due to the critical nature of the tasks to be performed by the extravehicular astronaut and because of deficiencies in presently operational simulations of relatively long duration, zero-gravity task performance, a technique has been proposed and evaluated wherein a pressure-suited subject is immersed in water and maintained in a neutrally buoyant condition to simulate the external tractionless characteristics of the zero-gravity environment. This technique provides the subject with six degrees of freedom without requiring the attendant encumbrance of connecting life-support or structural-support elements. Further, the technique provides the capability to perform the task functions in real time. The feasibility study performed in conjunction with this program indicates the following conclusions:

(1) Water-immersion weightless simulation techniques are practical for studying the external tractionless characteristics of astronaut performance in intervehicular and extravehicular tasks, particularly with regard to pressure-suit operations.

(2) Drag effects attendant upon operation in the water-immersion simulation are negligible when the tasks impose low velocity requirements on the motions involved and the range of motion is restricted, as in the case of air-lock ingress-egress and similar intravehicular tasks. Velocities should be limited to 2 fps (0.61 m/sec) or less.

(3) The combination of results from similar experiments made in zero-gravity aircraft with the more complete studies made possible by the water-immersion technique are complementary and should be used to provide a more accurate description of the zero-gravity phenomena.

(4) Water-immersion simulation for both the zero- and reduced-gravity conditions can be applied to many current and future space missions and tasks such as:

(a) The study of ingress-egress problems through air locks and passageways.

(b) Design and development of space suits for extravehicular mobility of the astronaut.

(c) Study and evaluation of crew and cargo transfer techniques.

(d) Human factors affecting the design and development of space vehicle systems and hardware.

(e) Training astronauts for reduced- or zero-gravity conditions.

(f) Evaluation of the pressure-suited astronaut's work capabilities external to space vehicles.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., September 22, 1965.

REFERENCES

1. Hewes, Donald E.; and Spady, Amos A., Jr.: Evaluation of a Gravity-Simulation Technique for Studies of Man's Self-Locomotion in Lunar Environment. NASA TN D-2176, 1964.

2. Trout, Otto F., Jr.: Water Immersion Techniques for the Study of a Pressure-Suited Astronaut Under Balanced Gravity Conditions. Paper presented to Human Factors Society Symposium (Washington, D.C.), Oct. 21, 1964.

3. Loats, Harry L., Jr.; and Mattingly, G. Samuel: A Study of the Performance of an Astronaut During Ingress and Egress Maneuvers Through Airlocks and Passageways. ERA 64-6(Contract NAS1-4059), Environ. Research Associates, Aug. 31, 1964.

4. Stone, Ralph W., Jr.; and Letko, William: Some Observations During Weightlessness Simulation With Subject Immersed in a Rotating Water Tank. NASA TN D-2195, 1964.

5. Levine, Raphael B.: Null-Gravity Simulation. Paper presented at the 31st Annual Meeting of the Aerospace Medical Association, May 9-11, 1960.

6. Graveline, Duane E.: Maintenance of Cardiovascular Adaptability During Prolonged Weightlessness. Aerospace Med., vol. 33, no. 3, Mar. 1962, pp. 297-302.

7. Schmitt, Thomas J.: Wind-Tunnel Investigation of Air Loads on Human Beings. Rept. 892 (Aero 858), David W. Taylor Model Basin, Navy Dept., Jan. 1954.

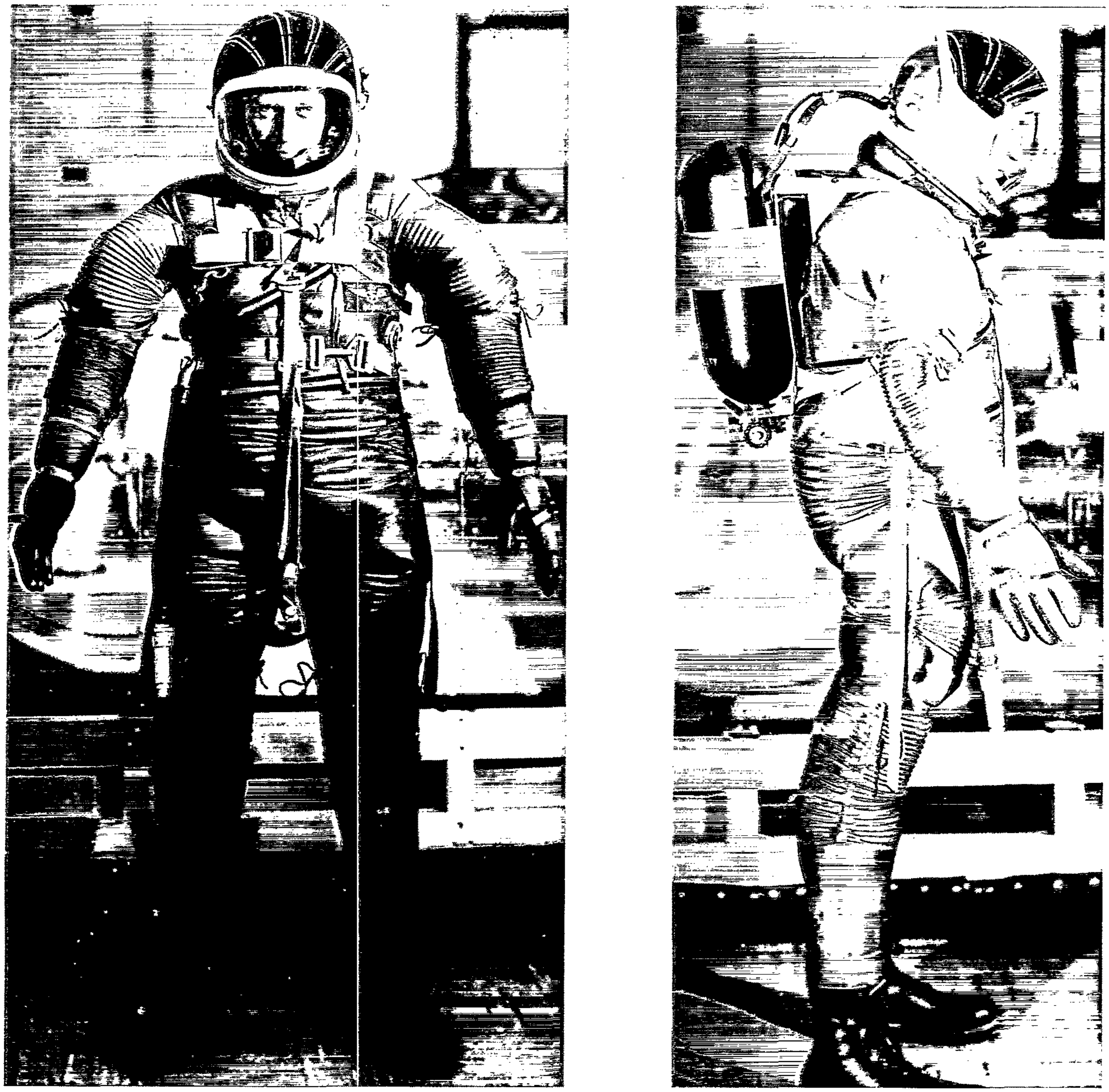

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Figure 1.- U.S. Navy Mark IV full pressure suit at 3.5 psig (24.1 kN/m^2).

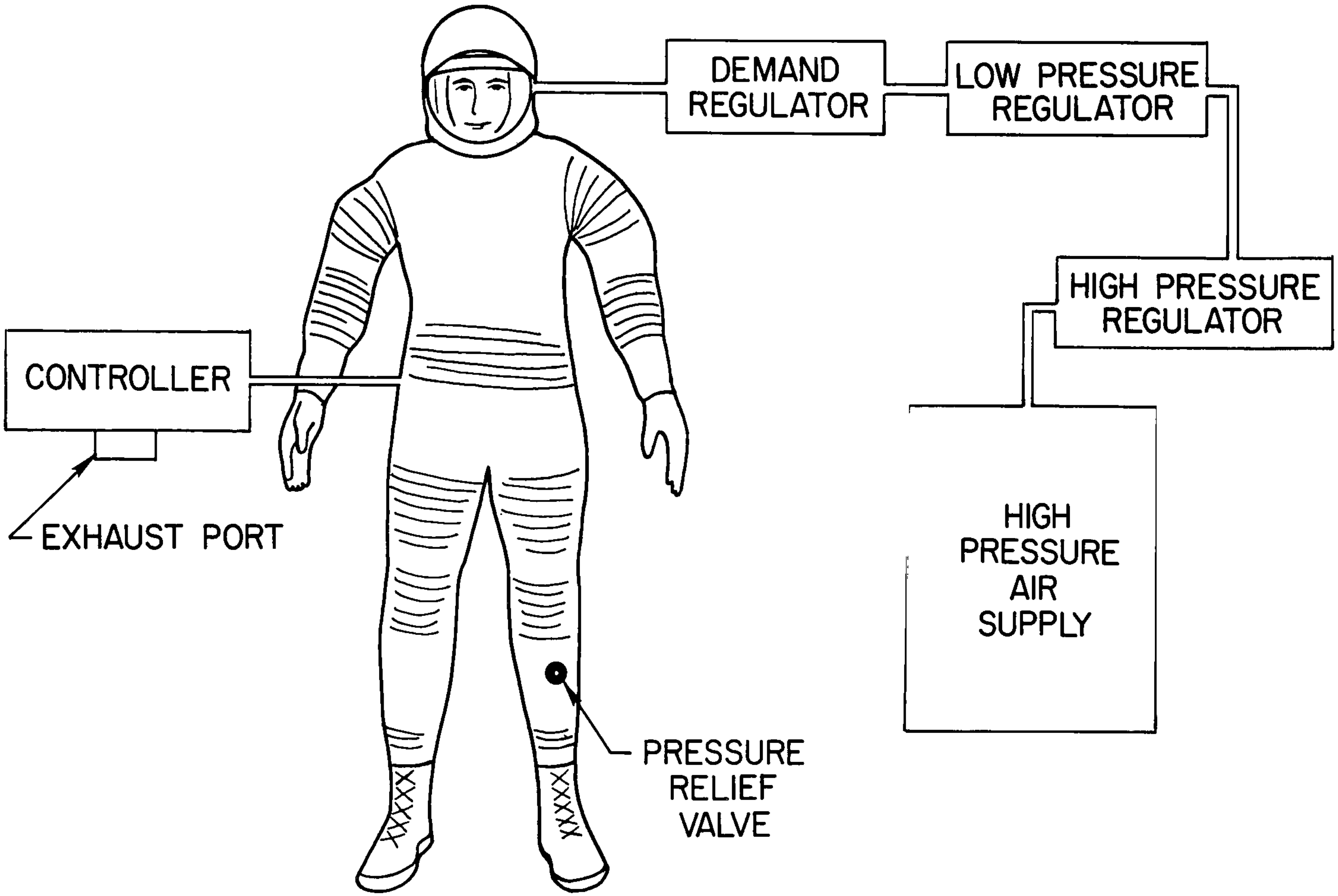
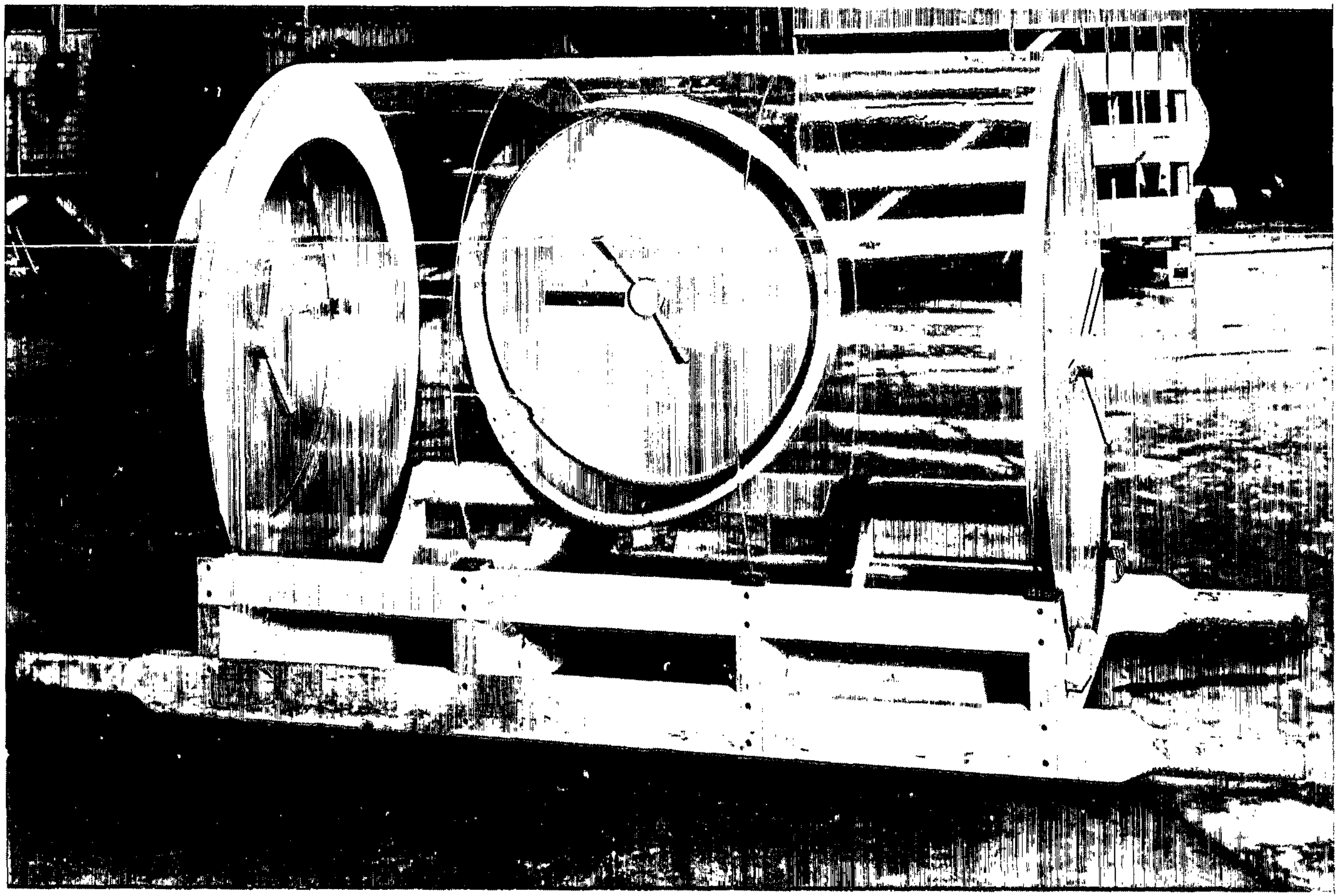
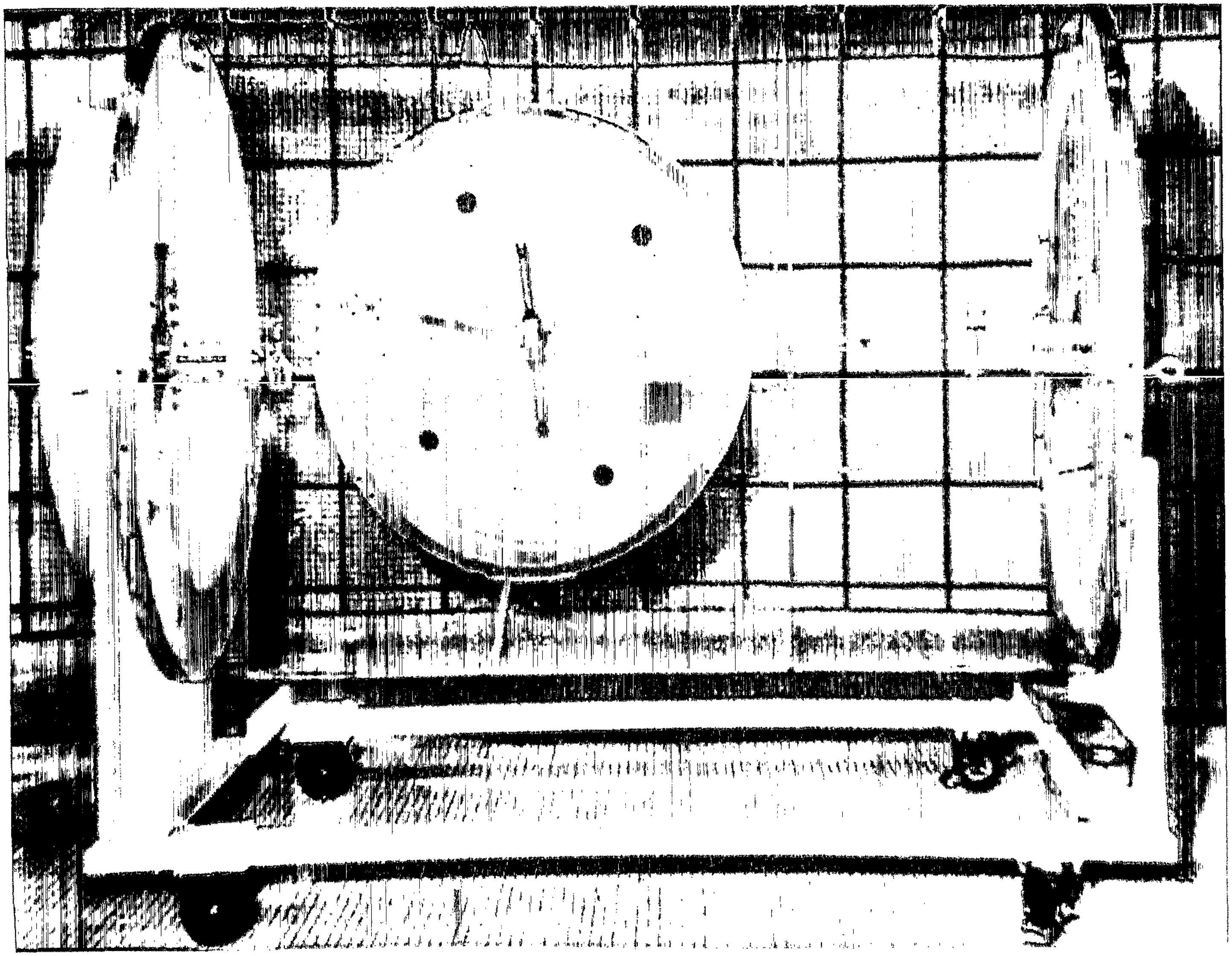


Figure 2.- Diagram of modified breathing-pressurization system for pressure suit.



(a) Model used in ground and aircraft tests. L-65-7915

Figure 3.- Air-lock test model.



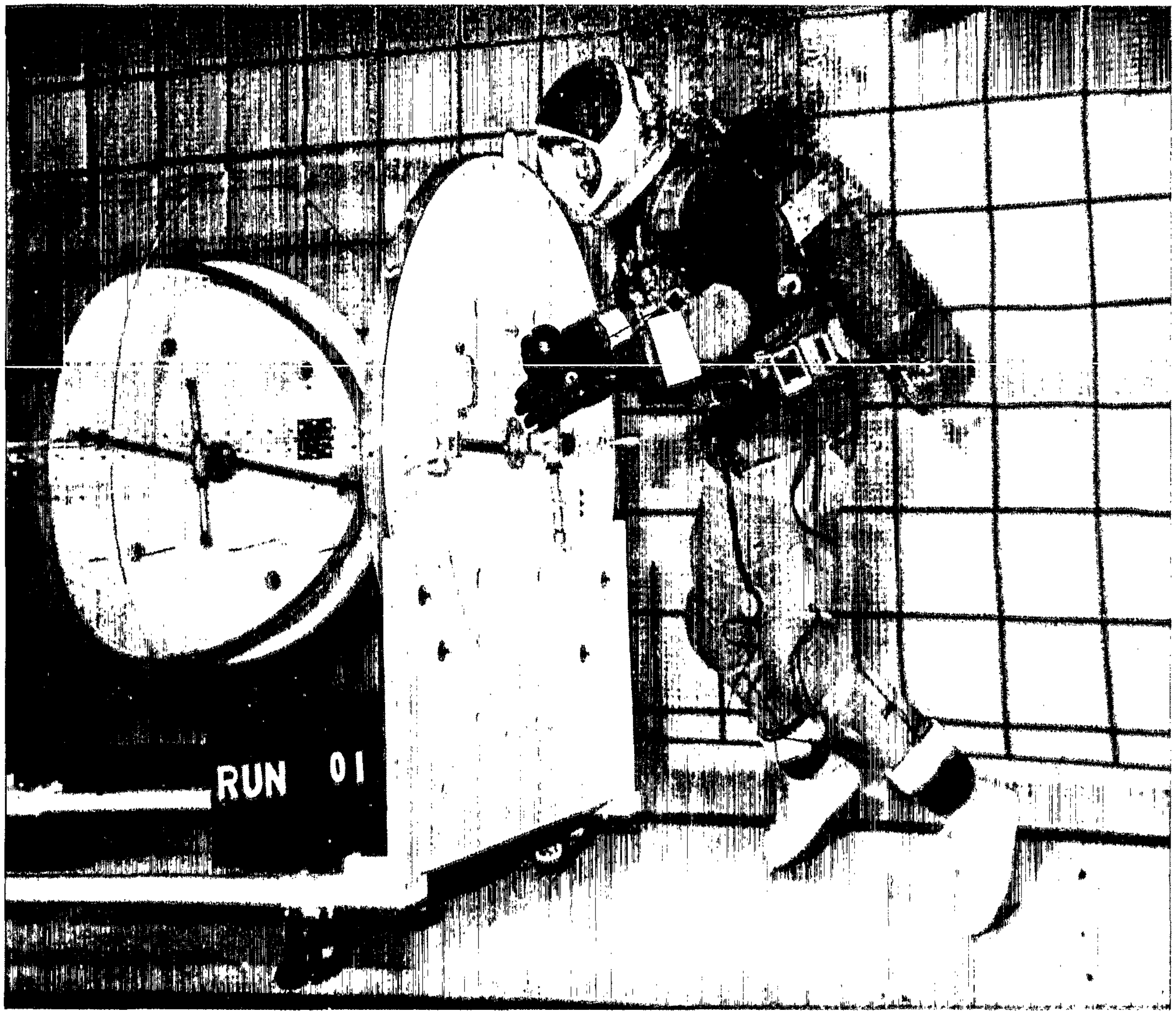
L-65-7916

(b) Model used in water-immersion tests.

Figure 3.- Concluded.

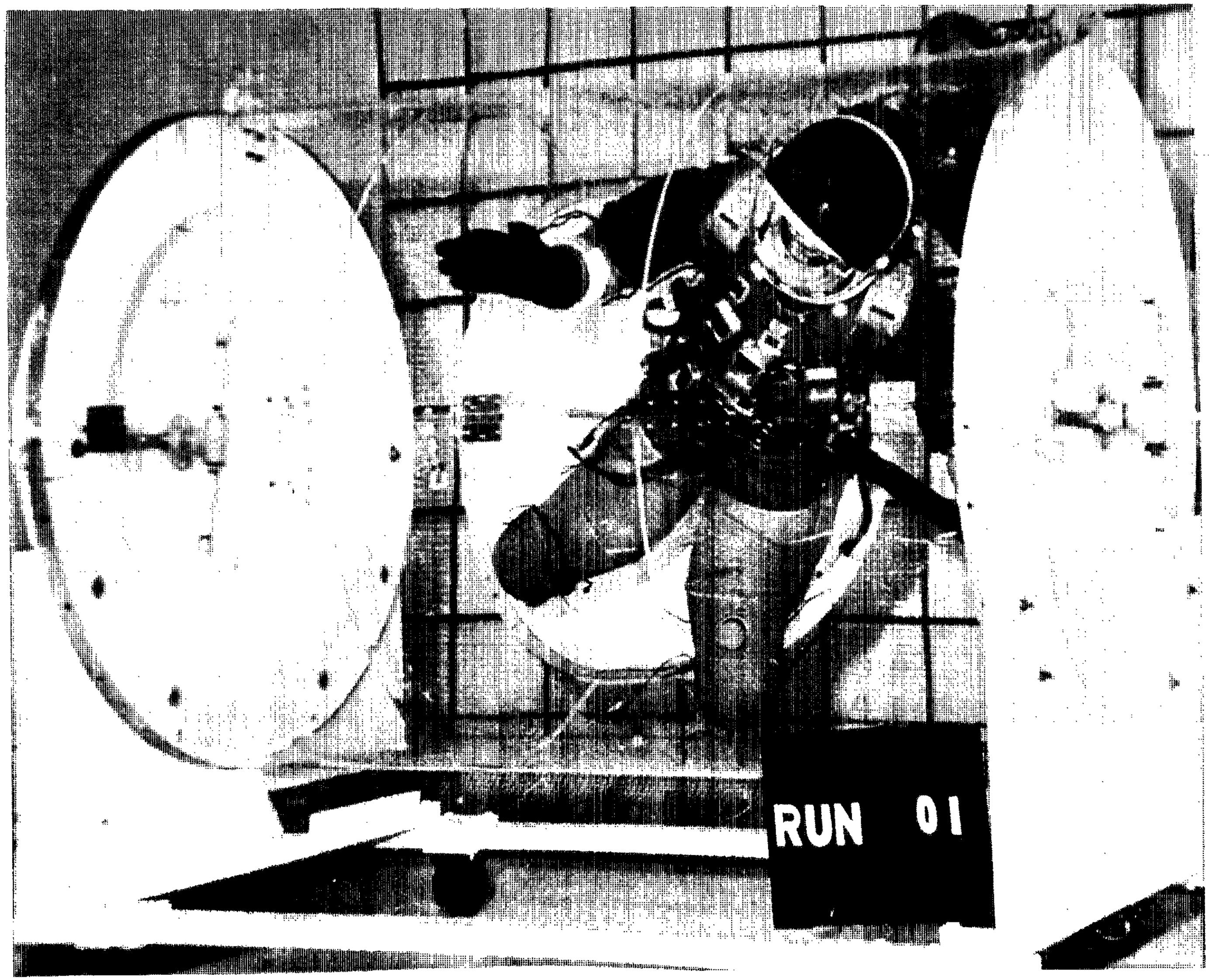
L-65-7917

Figure 4.- Pressure-suited subject showing placement of external weights.



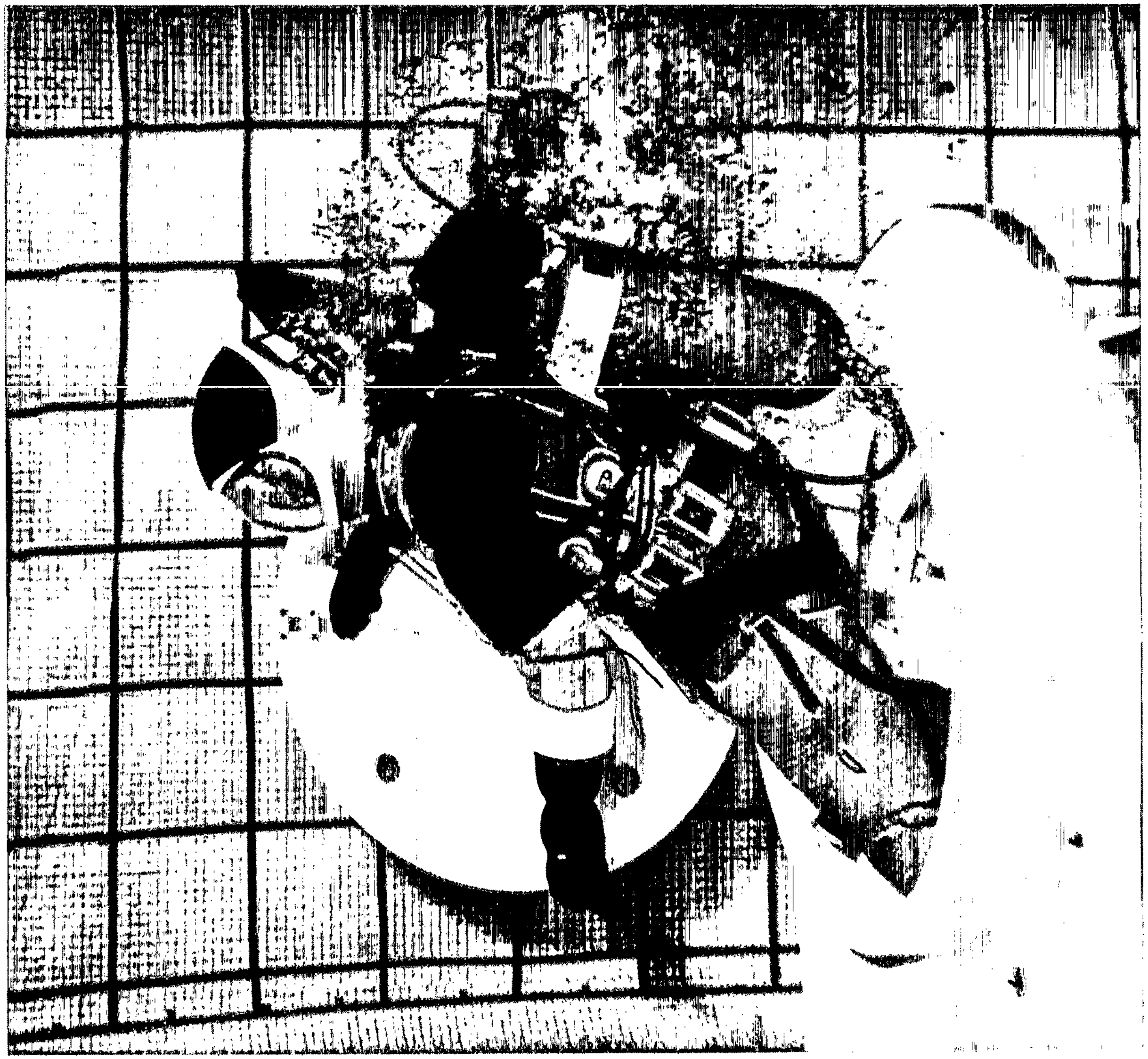
(a) Hatch operation on ingress. L-65-7918

Figure 5.- Pressure-suited subject during water-immersion simulation.



(b) Turnaround maneuver inside air lock. L-65-7919

Figure 5.- Continued.



(c) Egress from air lock. L-65-7920

Figure 5.- Concluded.

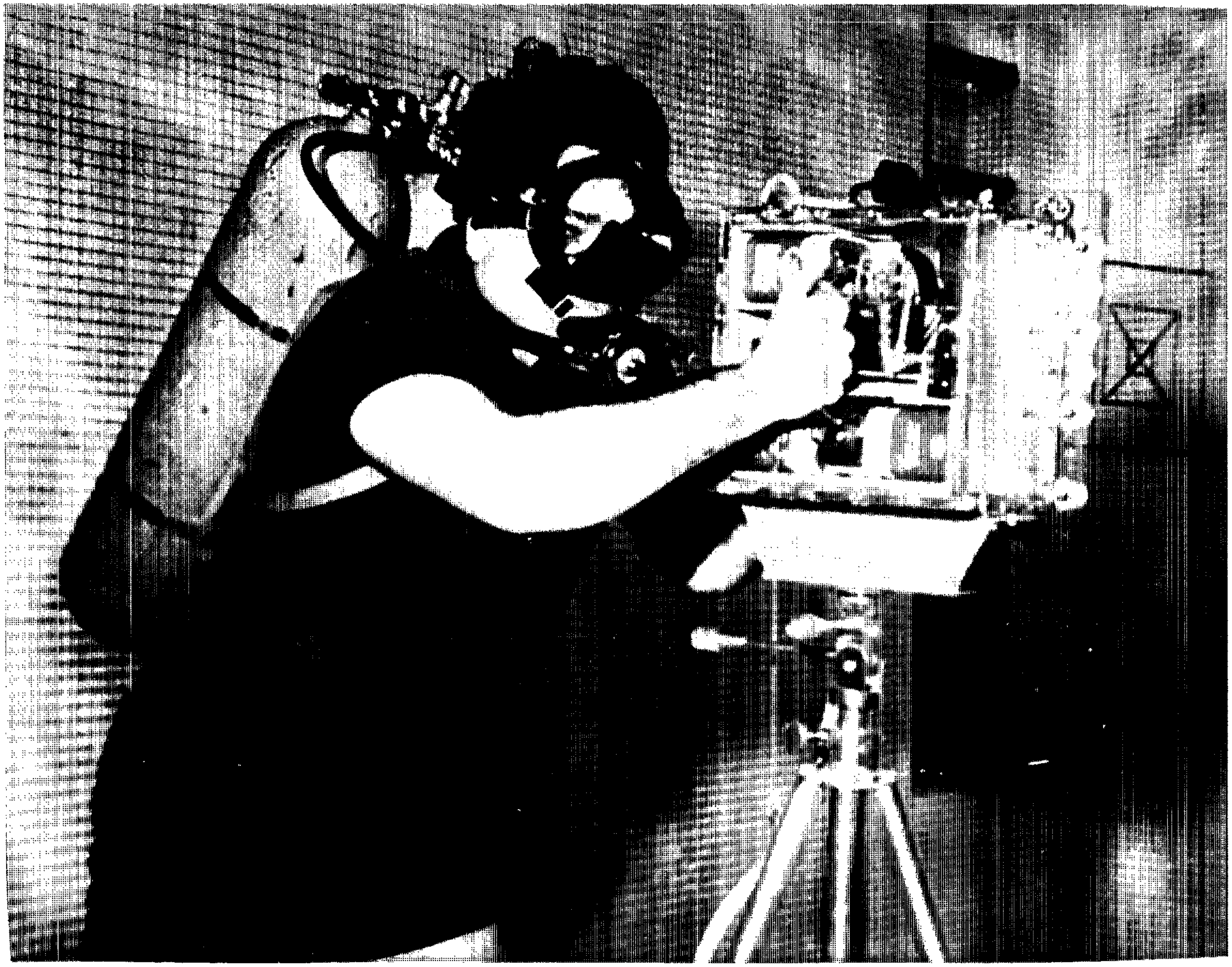
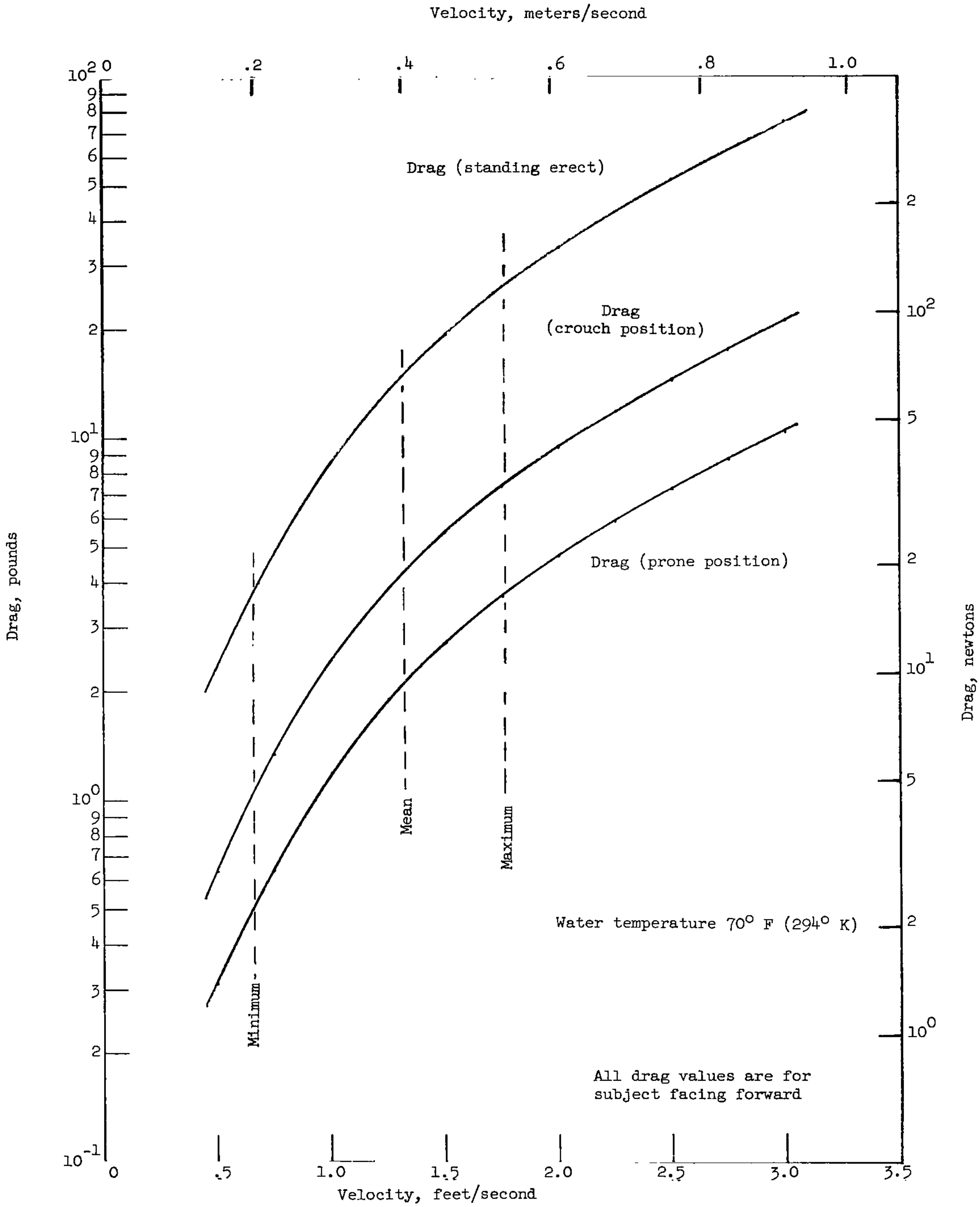
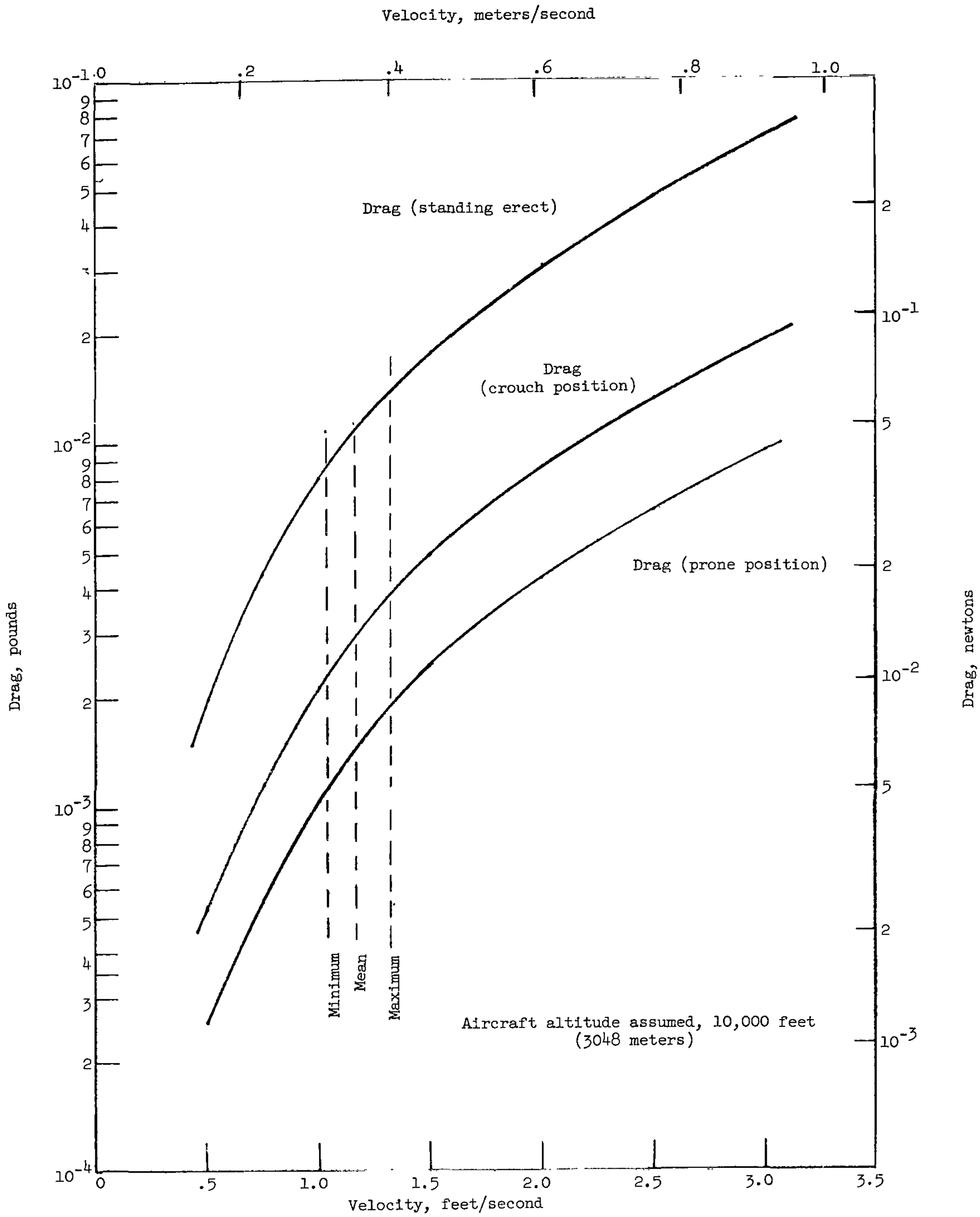


Figure 6.- Underwater camera. L-65-7921



(a) Water-immersion simulation.

Figure 7.- Variation of calculated drag with velocity for water-immersion and aircraft tests.



(b) Aircraft simulation.

Figure 7.- Concluded.

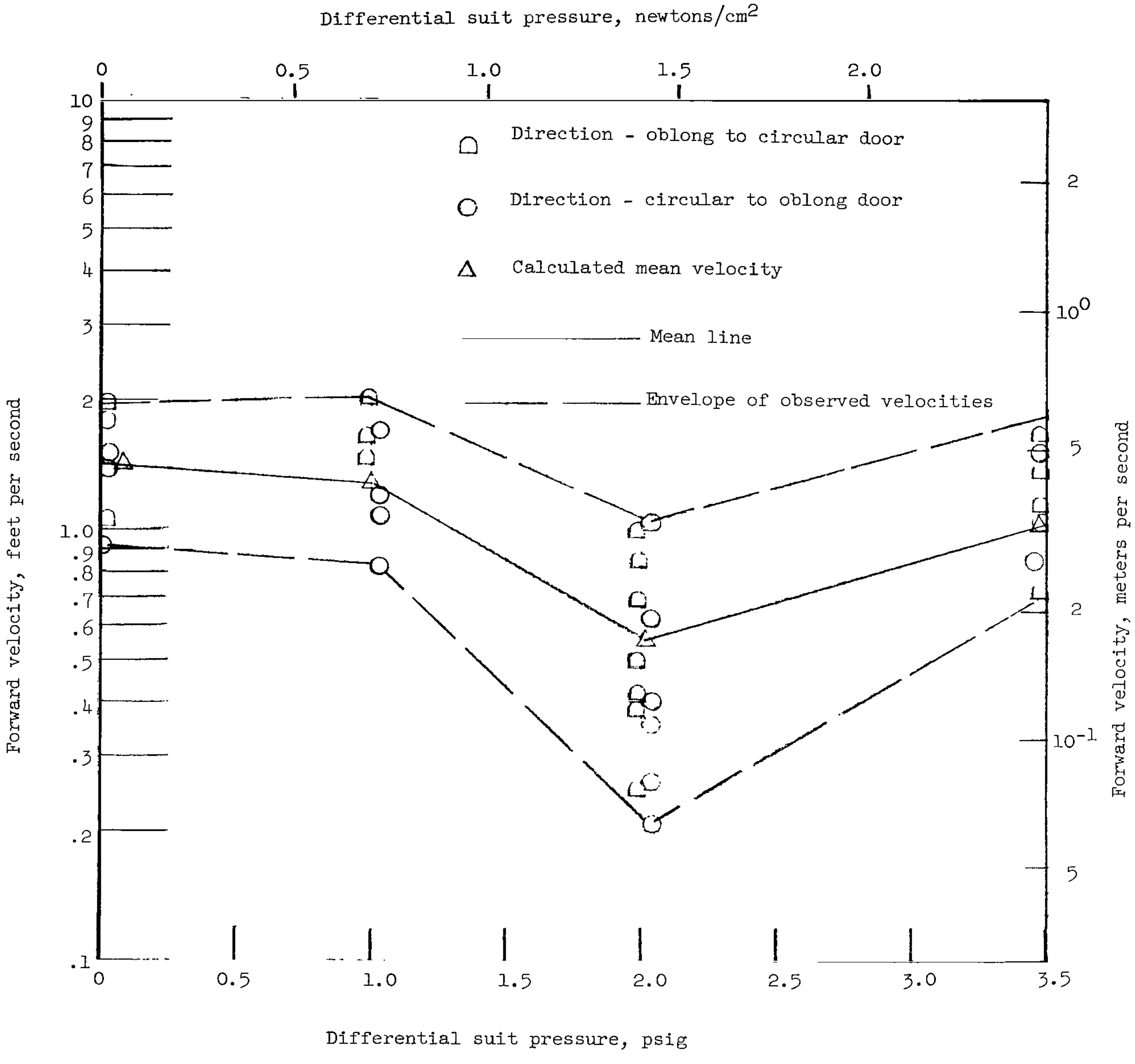
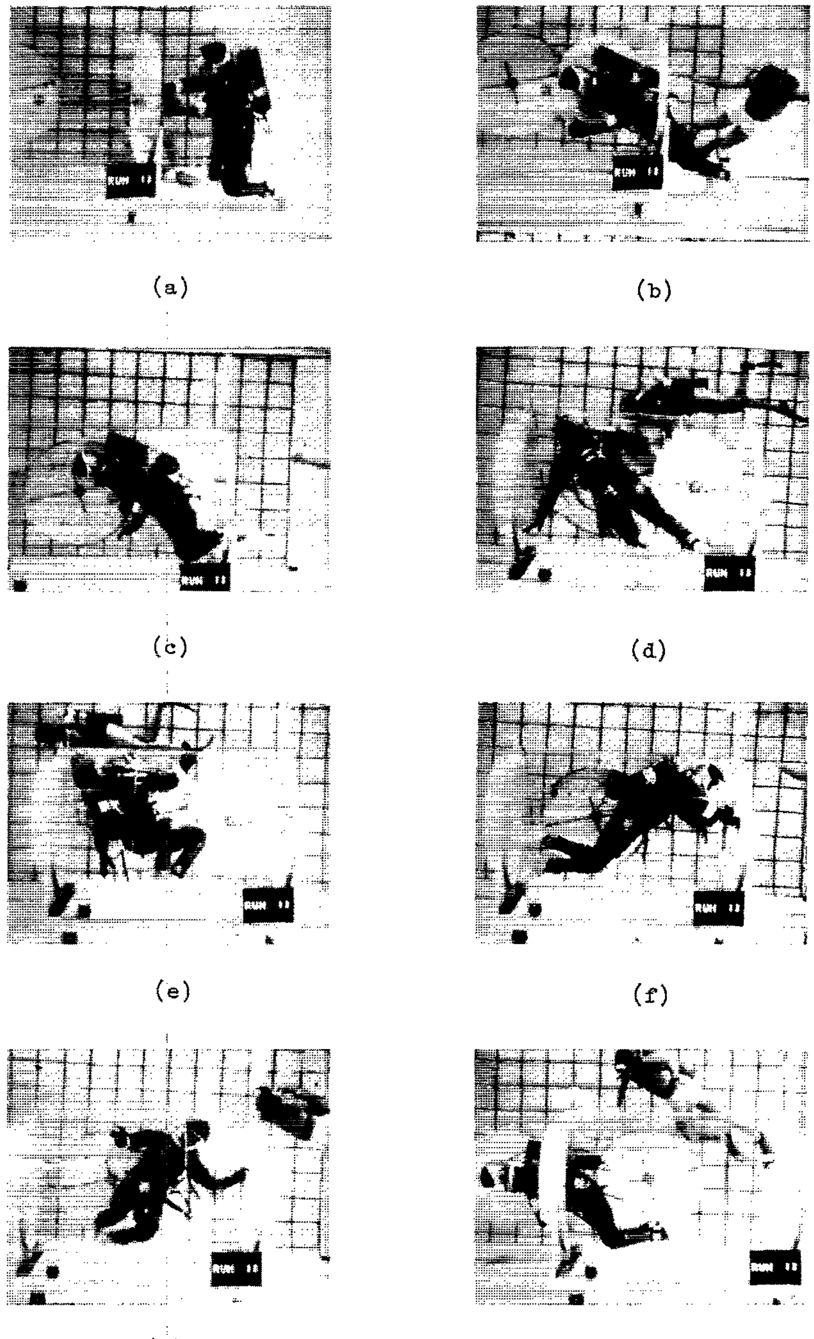


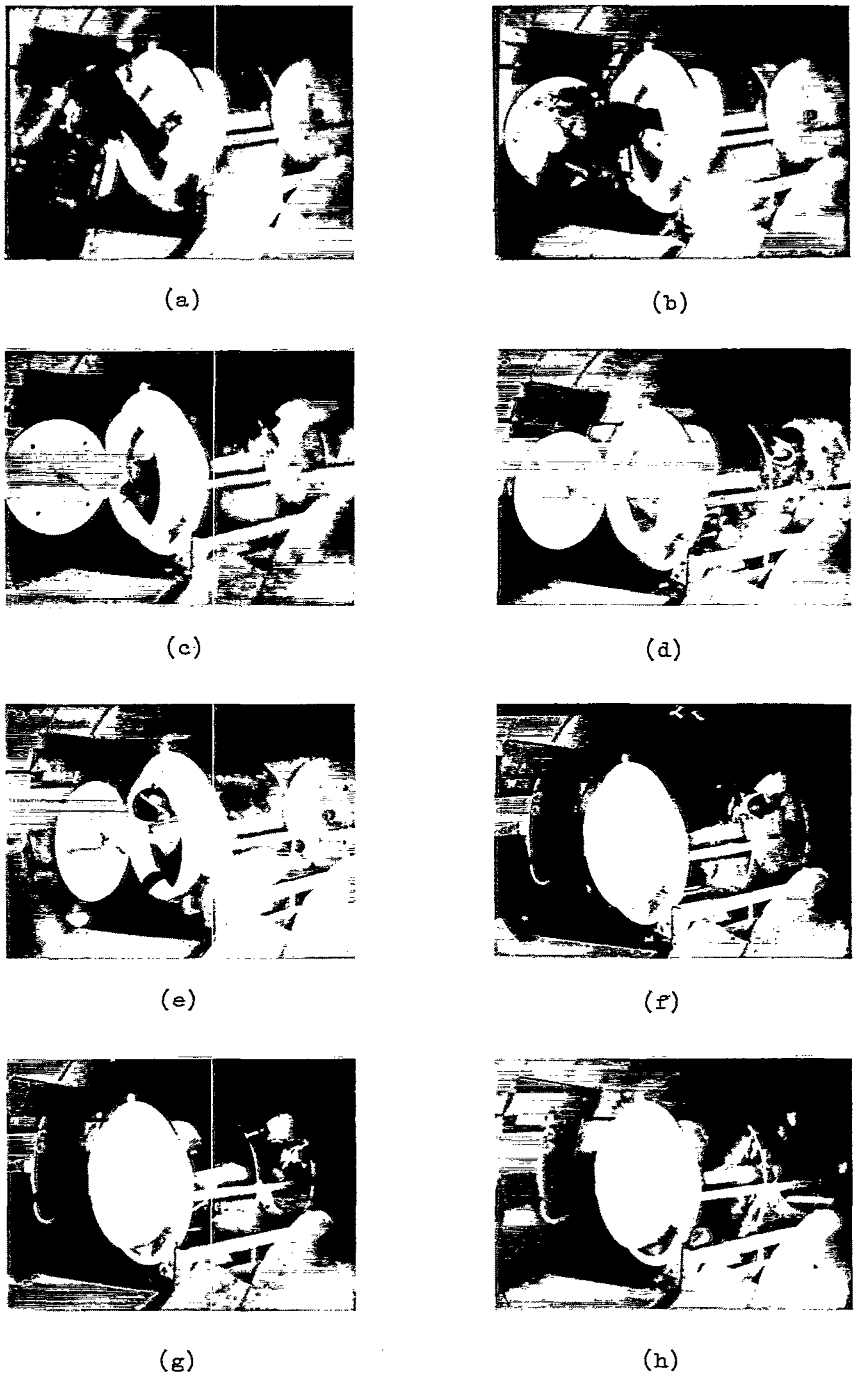
Figure 8.- Variation of observed forward velocity during ingress-egress maneuvers in water-immersion simulation with suit pressure.



(a) (b) (c) (d) (e) (f) (g) (h)

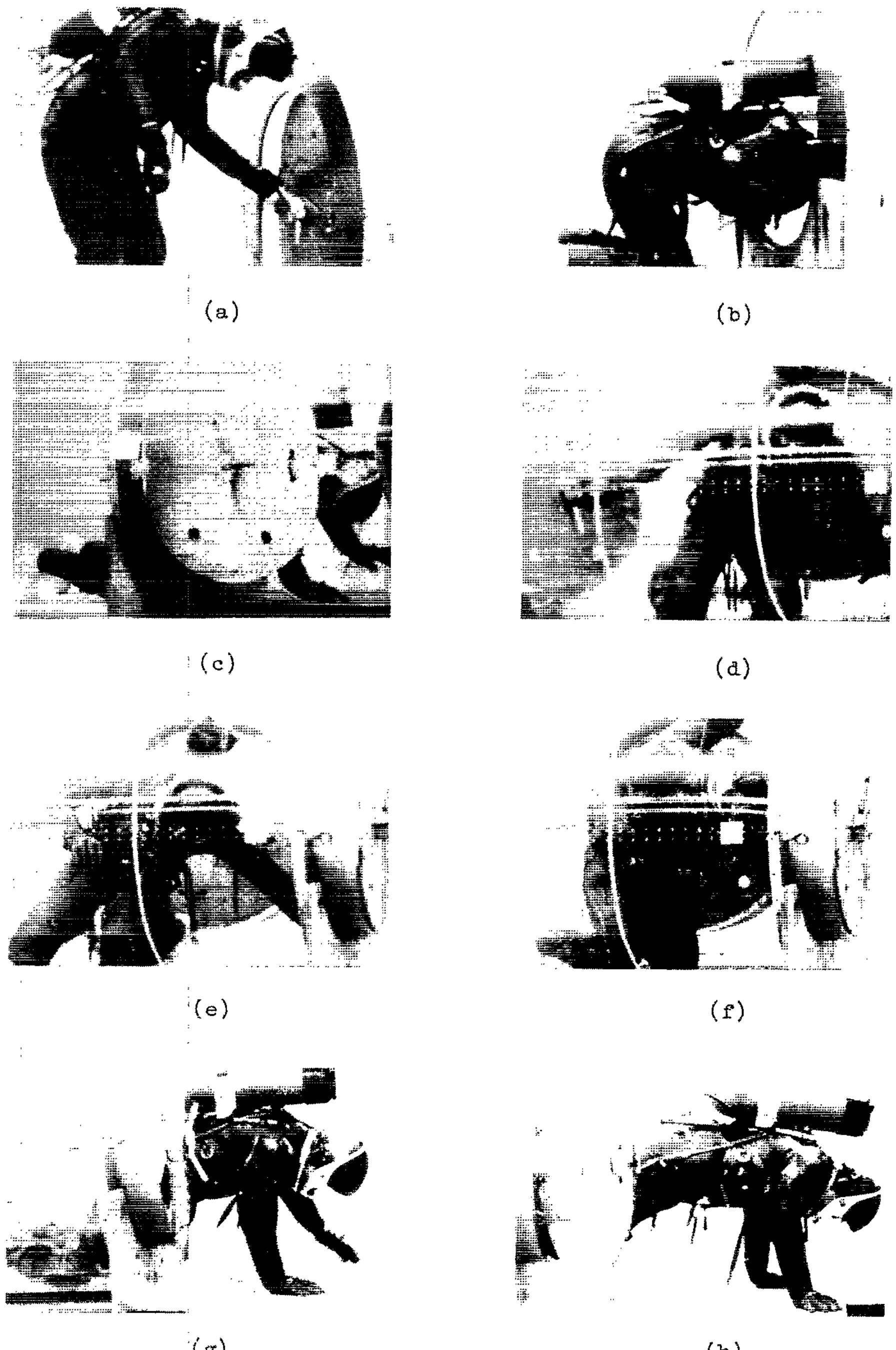
L-65-7922

Figure 9.- Photographic sequence of pressure-suited subject making passage through air lock during water-immersion simulation.



L-65-7923

Figure 10.- Photographic sequence of pressure-suited subject making passage through air lock during zero-gravity aircraft simulation.



L-65-7924

Figure 11.- Photographic sequence of pressure-suited subject making passage through air lock during ground tests.

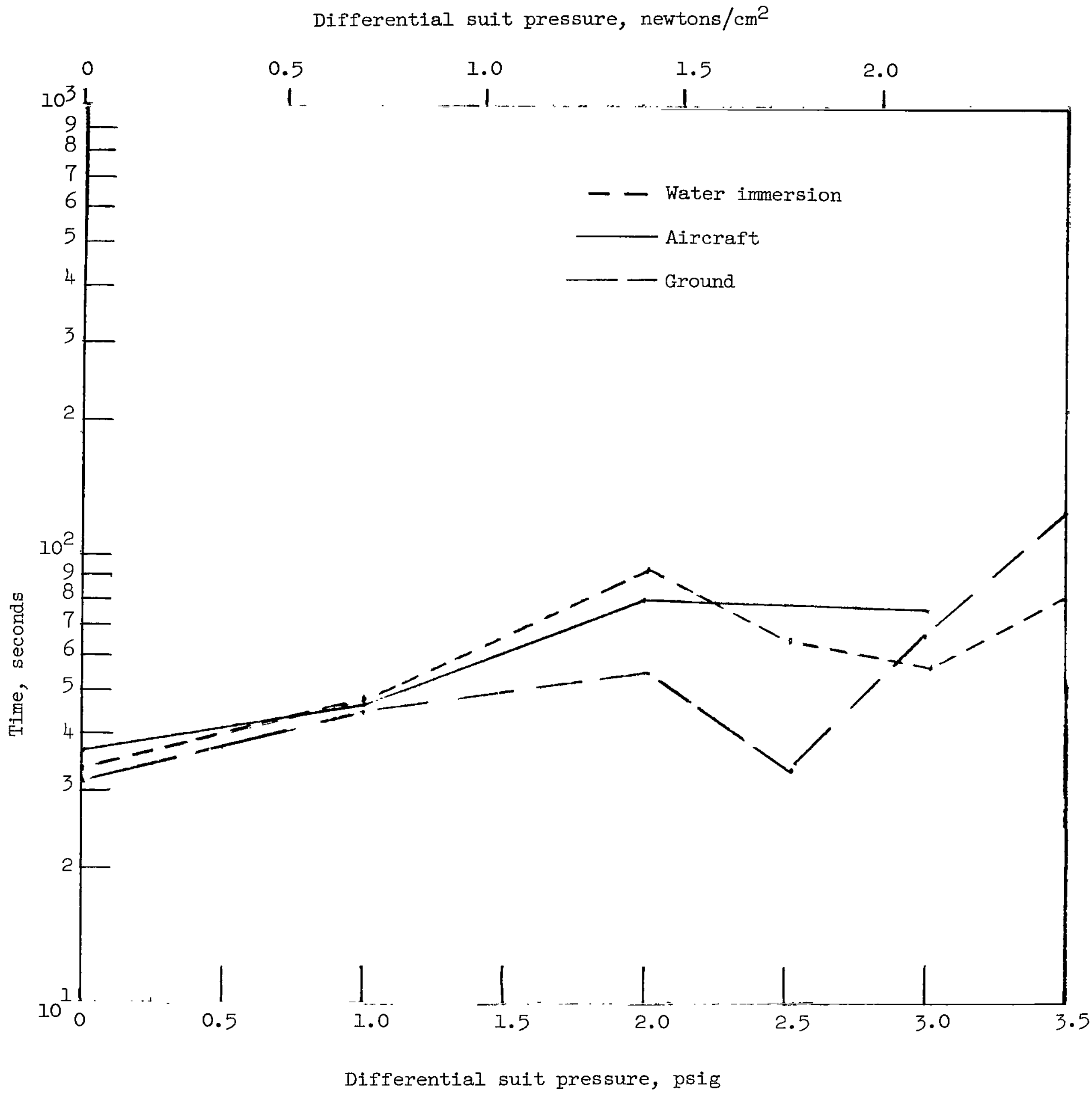
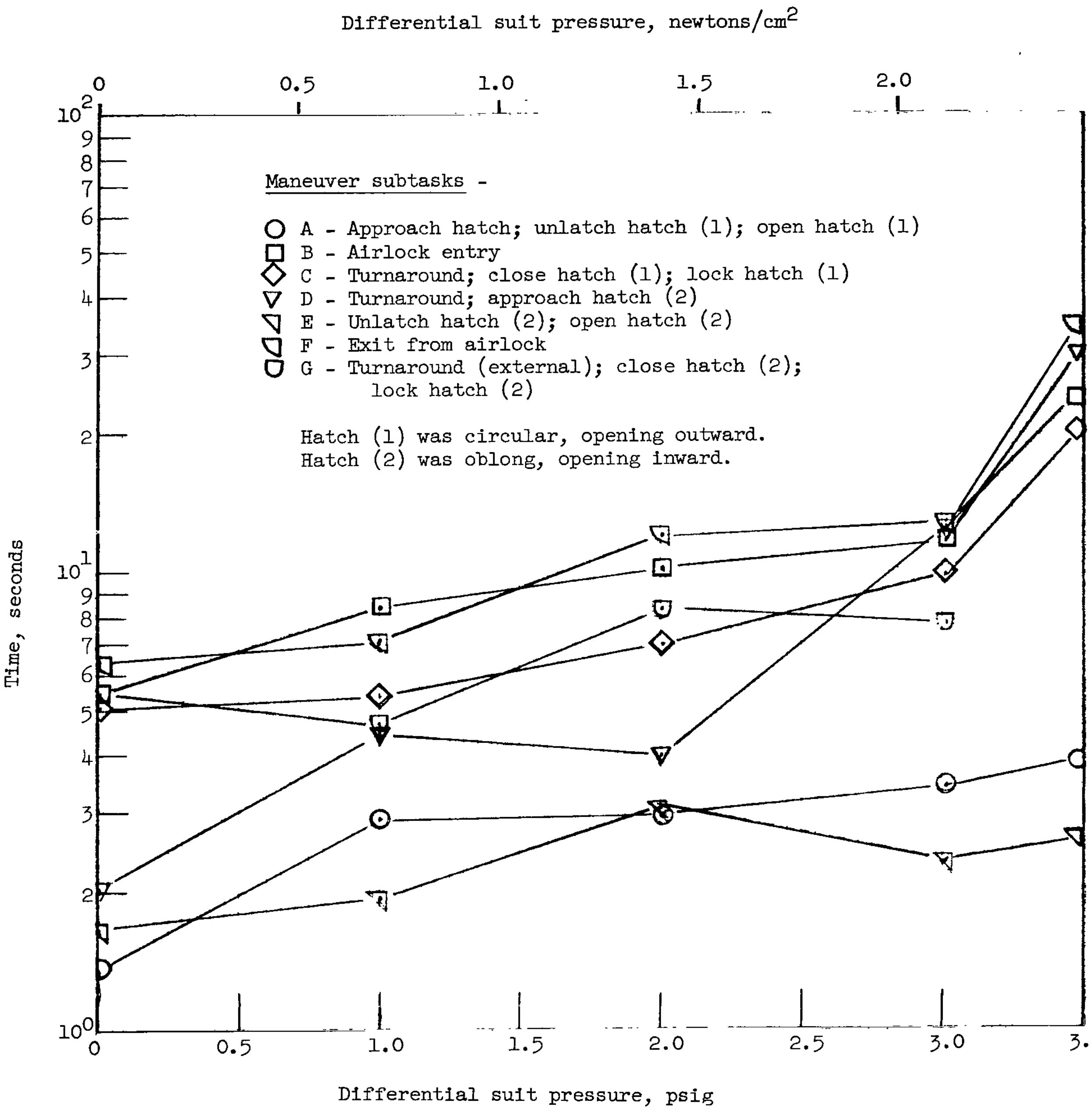
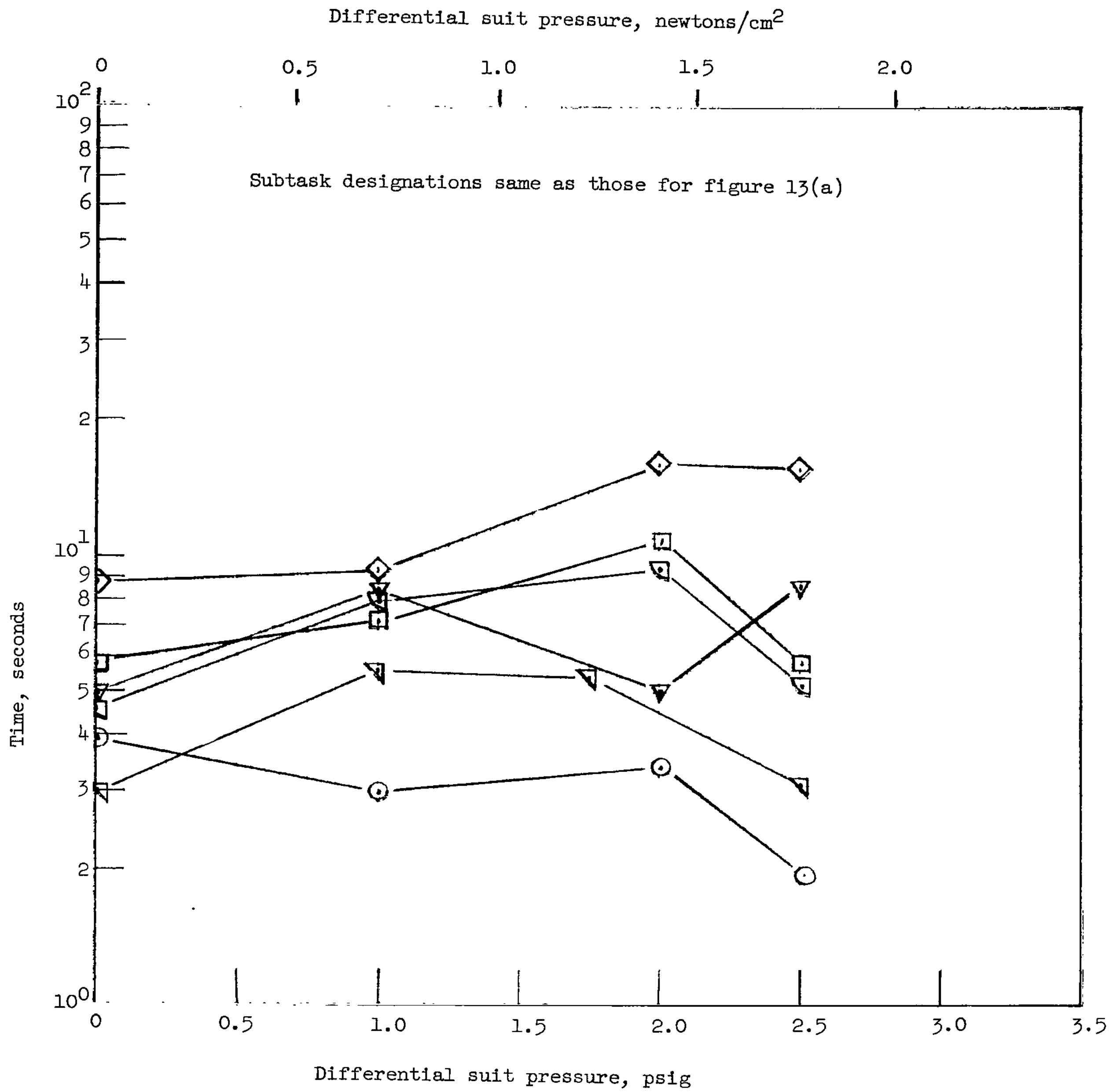


Figure 12.- Observed total ingress-egress times at various suit pressures for water-immersion, ground, and aircraft tests.



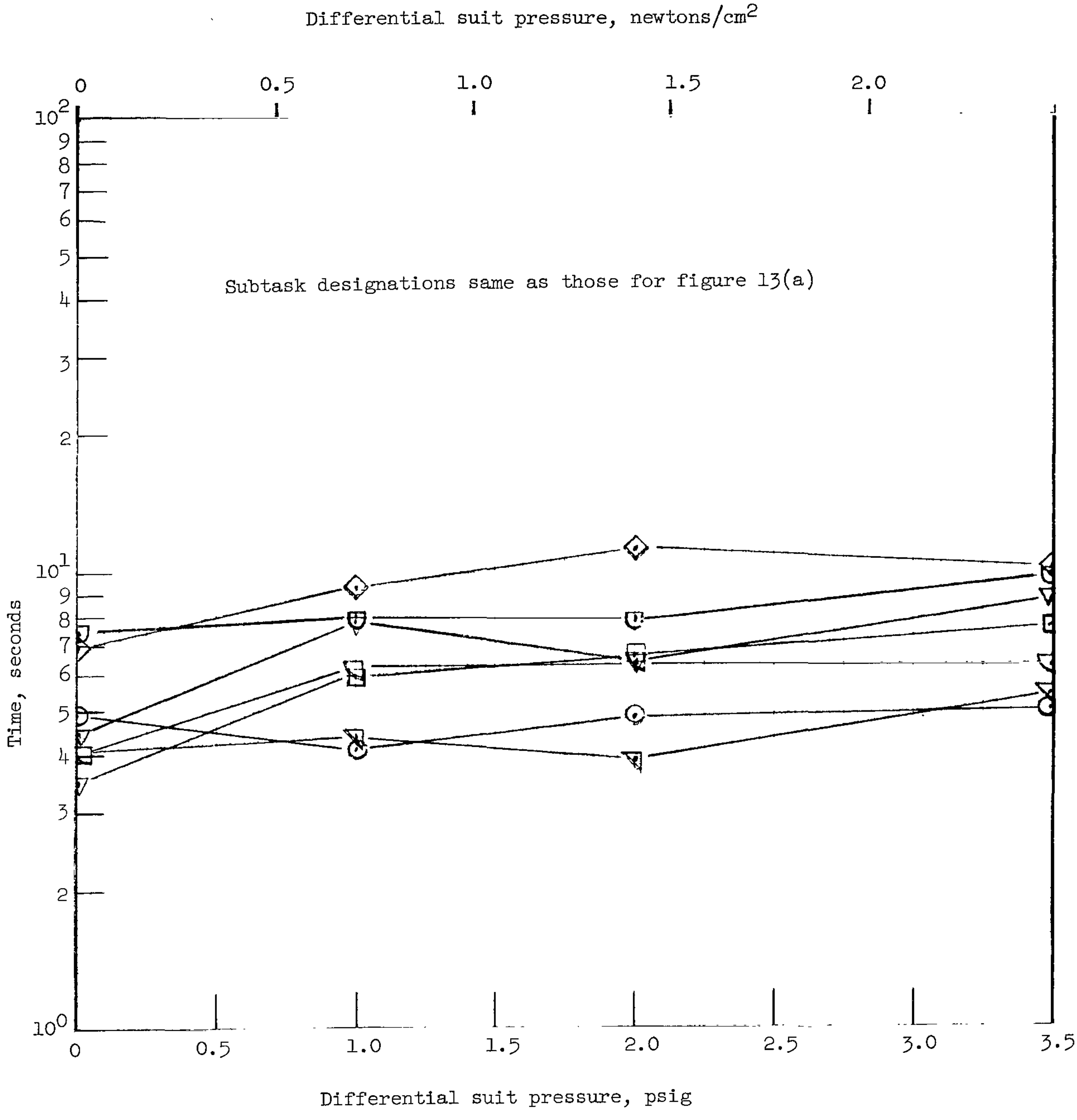
(a) Ground test.

Figure 13.- Subtask performance time for various suit pressures.



(b) Aircraft test.

Figure 13.- Continued.



(c) Water-immersion test.

Figure 13.- Concluded.

NASA-Langley, 1966 L-4409

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